CLAIMS

1. (original) A method for processing audio signals, comprising:

receiving a plurality of audio signals, each audio signal having been generated by a different sensor of a microphone array; and

decomposing the plurality of audio signals into a plurality of eigenbeam outputs, wherein each eigenbeam output corresponds to a different eigenbeam for the microphone array and at least one of the eigenbeams has an order of two or greater.

2. (original) The invention of claim 1, wherein the eigenbeams correspond to spheroidal harmonics based on a spherical, oblate, or prolate configuration of the sensors in the microphone array.

3. (original) The invention of claim 1, wherein at least one of the eigenbeams has an order of at least three.

4. (original) The invention of claim 1, wherein the microphone array comprises the plurality of sensors mounted on an acoustically rigid sphere.

5. (original) The invention of claim 4, wherein one or more of the sensors are pressure sensors.

6. (original) The invention of claim 5, wherein at least one pressure sensor comprises a patch sensor operating as a spatial low-pass filter to avoid spatial aliasing resulting from relatively high frequency components in the audio signals.

7. (original) The invention of claim 6, wherein at least one patch sensor comprises a number of proximally configured, individual pressure sensors, wherein, for each such patch sensor, analog signals generated by the number of individual pressure sensors are combined before sampling to generate a digital audio signal for that patch sensor.

8. (previously presented) The invention of claim 6, wherein the at least one pressure sensor further comprises a point sensor, wherein:

the point sensor is used to generate relatively low frequency audio signals; and

the patch sensor is used to generate relatively high frequency audio signals.

9. (original) The invention of claim 4, wherein one or more of the sensors are elevated over the surface of the sphere.

10. (previously presented) The invention of claim 1, wherein the microphone array comprises the plurality of sensors mounted on an acoustically soft sphere comprising a gas-filled elastic shell such that impedance to sound propagation through the acoustically soft sphere is less than impedance to sound propagation through liquid medium outside of the sphere.

11. (original) The invention of claim 10, wherein one or more of the sensors are cardioid sensors configured with their nulls pointing towards the center of the sphere.

12. (original) The invention of claim 1, wherein the number and positions of sensors in the microphone array enable representation of a beampattern as a series expansion involving at least second-order spheroidal harmonics.

13. (original) The invention of claim 12, wherein the number of sensors is based on the highest-order spheroidal harmonic in the series expansion.

14. (original) The invention of claim 1, wherein the arrangement of the sensors in the microphone array satisfies a discrete orthogonality condition.

15. (original) The invention of claim 1, wherein decomposing the plurality of audio signals further comprises treating each sensor signal as a directional beam for relatively high frequency components in the audio signals.

16. (original) The invention of claim 1, further comprising generating an auditory scene based on the eigenbeam outputs and their corresponding eigenbeams.

17. (original) The invention of claim 16, wherein generating the auditory scene comprises independently generating two or more different auditory scenes based on the eigenbeam outputs and their corresponding eigenbeams.

18. (original) The invention of claim 16, wherein generating the auditory scene comprises:

applying a weighting value to each eigenbeam output to form a weighted eigenbeam; and

combining the weighted eigenbeams to generate the auditory scene.

19. (original) The invention of claim 1, further comprising storing data corresponding to the eigenbeam outputs for subsequent processing.

20. (original) The invention of claim 19, further comprising:

recovering the eigenbeam outputs from the stored data; and

generating an auditory scene based on the recovered eigenbeam outputs and their corresponding eigenbeams.

21. (original) The invention of claim 1, further comprising transmitting data corresponding to the eigenbeam outputs for remote receipt and processing.

22. (original) The invention of claim 21, further comprising:

recovering the eigenbeam outputs from the received data; and

generating an auditory scene based on the recovered eigenbeam outputs and their corresponding eigenbeams.

23. (original) The invention of claim 1, further comprising applying an equalizer filter to each eigenbeam output to compensate for frequency dependence of the corresponding eigenbeam.

24. (original) The invention of claim 1, wherein receiving the plurality of audio signals further comprises generating the plurality of audio signals using the microphone array.

25. (original) The invention of claim 24, wherein receiving the plurality of audio signals further comprises calibrating each sensor of the microphone array based on measured data generated by the sensor.

26. (original) The invention of claim 25, wherein receiving the plurality of audio signals comprises calibrating each sensor of the microphone array using a calibration module comprising a reference sensor and an acoustic source configured on an enclosure having an open side, wherein the open side of the volume is held on top of the sensor in order to calibrate the sensor relative to the reference sensor.

27. (original) The invention of claim 1, wherein the plurality of sensors are arranged in two or more concentric arrays of sensors, wherein each array is adapted for audio signals in a different frequency range.

28. (original) The invention of claim 27, wherein audio signals from different arrays are combined prior to being decomposed into a plurality of eigenbeams.

29. (original) The invention of claim 1, wherein all of the sensors are used to process relatively low-frequency signals, while only a subset of the sensors are used to process relatively high-frequency signals.

30. (original) The invention of claim 29, wherein only one of the sensors is used to process the relatively high-frequency signals.

31. (original) A microphone, comprising a plurality of sensors mounted in an arrangement, wherein the number and positions of sensors in the arrangement enable representation of a beampattern for the microphone as a series expansion involving at least one second-order eigenbeam.

32. (original) The invention of claim 31, wherein the series expansion involves an eigenbeam having order of at least three.

33. (original) The invention of claim 31, wherein the arrangement is one of spherical, oblate, or prolate.

34. (original) The invention of claim 31, wherein the plurality of sensors are mounted on an acoustically rigid sphere.

35. (original) The invention of claim 34, wherein the sensors are pressure sensors.

36. (original) The invention of claim 35, wherein at least one pressure sensor comprises a patch sensor operating as a spatial low-pass filter to avoid aliasing resulting from relatively high frequency components in the audio signals.

37. (original) The invention of claim 36, wherein at least one patch sensor comprises a number of proximally configured, individual pressure sensors, wherein, for each such patch sensor, analog signals generated by the number of individual pressure sensors are combined before sampling to generate a digital audio signal for that patch sensor.

38. (previously presented) The invention of claim 36, wherein the at least one pressure sensor further comprises a point sensor, wherein:

the point sensor is used to generate relatively low frequency audio signals; and

the patch sensor is used to generate relatively high frequency audio signals.

39. (original) The invention of claim 34, wherein one or more of the sensors are elevated over the surface of the sphere.

40. (previously presented) The invention of claim 31, wherein the plurality of sensors are mounted on an acoustically soft sphere comprising a gas-filled elastic shell such that impedance to sound propagation through the acoustically soft sphere is less than impedance to sound propagation through liquid medium outside of the sphere.

41. (original) The invention of claim 40, wherein the sensors are cardioid sensors configured with their nulls pointing towards the center of the sphere.

42. (original) The invention of claim 31, wherein the second-order eigenbeam corresponds to a second-order spheroidal harmonic.

43. (original) The invention of claim 42, wherein the number of sensors is based on the highest-order spheroidal harmonic in the series expansion.

44. (original) The invention of claim 31, wherein the arrangement of the sensors satisfies a discrete orthogonality condition.

45. (original) The invention of claim 31, further comprising a processor configured to decompose a plurality of audio signals generated by the sensors into a plurality of eigenbeam outputs, wherein each eigenbeam output corresponds to a different eigenbeam for the microphone array and at least one of the eigenbeams has an order of two or greater.

46. (original) The invention of claim 45, wherein the processor is further configured to generate an auditory scene based on the eigenbeam outputs and their corresponding eigenbeams.

47. (original) The invention of claim 31, wherein the plurality of sensors are arranged in two or more concentric arrays of sensors, wherein each array is adapted for audio signals in a different frequency range.

48. (original) The invention of claim 47, wherein the sensors in the different arrays are located at the same spherical coordinates.

49. (original) The invention of claim 31, wherein all of the sensors are used to process relatively low-frequency signals, while only a subset of the sensors are used to process relatively high-frequency signals.

50. (original) The invention of claim 49, wherein only one of the sensors is used to process the relatively high-frequency signals.

51. (original) A method for generating an auditory scene, comprising:

receiving eigenbeam outputs, the eigenbeam outputs having been generated by decomposing a plurality of audio signals, each audio signal having been generated by a different sensor of a microphone array, wherein each eigenbeam output corresponds to a different eigenbeam for the microphone array and at least one of the eigenbeam outputs corresponds to an eigenbeam having an order of two or greater; and

generating the auditory scene based on the eigenbeam outputs and their corresponding eigenbeams.

52. (original) The invention of claim 51, wherein generating the auditory scene comprises:

applying a weighting value to each eigenbeam output to form a weighted eigenbeam; and

combining the weighted eigenbeams to generate the auditory scene.

53. (original) The invention of claim 51, wherein generating the auditory scene further comprises applying an equalizer filter to each eigenbeam output to compensate for frequency dependence of the corresponding eigenbeam.

54. (original) The invention of claim 51, wherein the microphone array comprises a plurality of sensors mounted in a spheroidal arrangement.

55. (original) The invention of claim 54, wherein the plurality of sensors are mounted on an acoustically rigid sphere.

56. (original) The invention of claim 55, wherein the sensors are pressure sensors.

57. (original) The invention of claim 56, wherein at least one pressure sensor comprises a patch sensor operating as a spatial low-pass filter to avoid aliasing resulting from relatively high frequency components in the audio signals.

58. (original) The invention of claim 57, wherein at least one patch sensor comprises a number of proximally configured, individual pressure sensors, wherein, for each such patch sensor, analog signals generated by the number of individual pressure sensors are combined before sampling to generate a digital audio signal for that patch sensor.

59. (previously presented) The invention of claim 57, wherein the at least one pressure sensor further comprises a point sensor, wherein:

the point sensor is used to generate relatively low frequency audio signals; and

the patch sensor is used to generate relatively high frequency audio signals.

60. (original) The invention of claim 55, wherein one or more of the sensors are elevated over the surface of the sphere.

61. (previously presented) The invention of claim 54, wherein the plurality of sensors are mounted on an acoustically soft sphere comprising a gas-filled elastic shell such that impedance to sound propagation through the acoustically soft sphere is less than impedance to sound propagation through liquid medium outside of the sphere.

62. (original) The invention of claim 61, wherein one or more of the sensors are cardioid sensors configured with their nulls pointing towards the center of the sphere.

63. (original) The invention of claim 54, wherein the number and positions of sensors in the microphone array enable representation of a beampattern as a series expansion involving at least second-order spheroidal harmonics.

64. (original) The invention of claim 63, wherein the number of sensors is based on the highest-order spheroidal harmonic in the series expansion.

65. (original) The invention of claim 54, wherein the arrangement of the sensors satisfies a discrete orthogonality condition.

66. (original) The invention of claim 51, wherein generating the auditory scene further comprises treating each sensor signal as a directional beam for relatively high frequency components in the audio signals.

67. (original) The invention of claim 51, wherein receiving the eigenbeam outputs further comprises recovering the eigenbeam outputs from data stored during previous processing.

68. (original) The invention of claim 51, wherein receiving the eigenbeam outputs further comprises recovering the eigenbeam outputs from data received after transmission from a remote node.

69. (original) The invention of claim 51, wherein the number of higher-order eigenbeams used in generating the auditory scene is limited to maintain a minimum value of signal-to-noise ratio (SNR).

70. (original) The invention of claim 69, wherein the SNR is characterized using white noise gain.

71. (original) The invention of claim 51, wherein generating the auditory scene comprises independently generating two or more different auditory scenes based on the eigenbeam outputs and their corresponding eigenbeams.

72. (original) The invention of claim 51, wherein the plurality of sensors are arranged in two or more concentric patterns, each pattern having a plurality of sensors adapted to process signals in a different frequency range.

73. (original) The invention of claim 72, wherein the sensors arranged in the innermost patterns are mounted on the surface of an acoustically rigid sphere.

74. (original) The invention of claim 51, wherein all of the sensors are used to process relatively low-frequency signals, while only a subset of the sensors are used to process relatively high-frequency signals.

75. (original) The invention of claim 74, wherein only one of the sensors is used to process the relatively high-frequency signals.

76. (previously presented) The invention of claim 16, wherein:

the auditory scene is a second-order or higher directional beam steered in a specified direction; and

generating the auditory scene comprises:

receiving the specified direction for the directional beam; and

generating the directional beam by combining the eigenbeam outputs based on the specified direction.

77. (previously presented) The invention of claim 46, wherein:

the auditory scene is a second-order or higher directional beam steered in a specified direction; and

the processor is further configured to generate the auditory scene by:

receiving the specified direction for the directional beam; and

generating the directional beam by combining the eigenbeam outputs based on the specified direction.

78. (previously presented) The invention of claim 51, wherein:

the auditory scene is a second-order or higher directional beam steered in a specified direction; and

generating the auditory scene comprises:

receiving the specified direction for the directional beam; and

generating the directional beam by combining the eigenbeam outputs based on the specified direction.

79. (new) The invention of claim 14, wherein the discrete orthogonality condition is substantially given by Formula (1) as follows:

$$\delta_{n-n',m-m'} \propto \frac{4\pi}{S}\sum_{s=1}^{S} Y_n^{m*}(p_s)Y_{n'}^{m'}(p_s) \quad , \qquad (1)$$

wherein:

$\delta_{n-n',m-m'}$ equals 1 when $n = n'$ and $m = m'$, and 0 otherwise;

S is the number of sensors in the microphone array;

p_s is position of sensor s in the microphone array;

$Y_{n'}^{m'}(p_s)$ is a spheroidal harmonic function of order n' and degree m' at position p_s; and

$Y_n^{m*}(p_s)$ is a complex conjugate of the spheroidal harmonic function of order n and degree m at position p_s.

80. (new) The invention of claim 79, wherein, for a spherical microphone array, the discrete orthogonality condition of Formula (1) is substantially given by Formula (2) as follows:

$$\delta_{n-n',m-m'} \propto \frac{4\pi}{S}\sum_{s=1}^{S} Y_n^{m*}(\vartheta_s,\varphi_s)Y_{n'}^{m'}(\vartheta_s,\varphi_s), \qquad (2)$$

wherein:

(ϑ_s,φ_s) are spherical coordinate angles of sensor s in the microphone array;

$Y_{n'}^{m'}(\vartheta_s,\varphi_s)$ is a spherical harmonic function of order n' and degree m' at the spherical coordinate angles (ϑ_s,φ_s); and

$Y_n^{m*}(\vartheta_s,\varphi_s)$ is a complex conjugate of the spherical harmonic function of order n and degree m at the spherical coordinate angles (ϑ_s,φ_s).

81. (new) The invention of claim 44, wherein the discrete orthogonality condition is substantially given by Formula (1) as follows:

$$\delta_{n-n',m-m'} \propto \frac{4\pi}{S}\sum_{s=1}^{S} Y_n^{m*}(p_s)\, Y_{n'}^{m'}(p_s) \quad , \qquad (1)$$

wherein:

$\delta_{n-n',m-m'}$ equals 1 when $n = n'$ and $m = m'$, and 0 otherwise;

S is the number of sensors in the microphone array;

p_s is position of sensor *s* in the microphone array;

$Y_{n'}^{m'}(p_s)$ is a spheroidal harmonic function of order *n'* and degree *m'* at position p_s; and

$Y_n^{m*}(p_s)$ is a complex conjugate of the spheroidal harmonic function of order *n* and degree *m* at position p_s.

82. (new) The invention of claim 81, wherein, for a spherical microphone array, the discrete orthogonality condition of Formula (1) is substantially given by Formula (2) as follows:

$$\delta_{n-n',m-m'} \propto \frac{4\pi}{S}\sum_{s=1}^{S} Y_n^{m*}(\vartheta_s,\varphi_s)\, Y_{n'}^{m'}(\vartheta_s,\varphi_s), \qquad (2)$$

wherein:

(ϑ_s,φ_s) are spherical coordinate angles of sensor *s* in the microphone array;

$Y_{n'}^{m'}(\vartheta_s,\varphi_s)$ is a spherical harmonic function of order *n'* and degree *m'* at the spherical coordinate angles (ϑ_s,φ_s); and

$Y_n^{m*}(\vartheta_s,\varphi_s)$ is a complex conjugate of the spherical harmonic function of order *n* and degree *m* at the spherical coordinate angles (ϑ_s,φ_s).

83. (new) The invention of claim 65, wherein the discrete orthogonality condition is substantially given by Formula (1) as follows:

$$\delta_{n-n',m-m'} \propto \frac{4\pi}{S}\sum_{s=1}^{S} Y_n^{m*}(p_s) Y_{n'}^{m'}(p_s) \quad , \qquad (1)$$

wherein:

$\delta_{n-n',m-m'}$ equals 1 when $n = n'$ and $m = m'$, and 0 otherwise;

S is the number of sensors in the microphone array;

p_s is position of sensor *s* in the microphone array;

$Y_{n'}^{m'}(p_s)$ is a spheroidal harmonic function of order *n'* and degree *m'* at position p_s; and

$Y_n^{m*}(p_s)$ is a complex conjugate of the spheroidal harmonic function of order *n* and degree *m* at position p_s.

84. (new) The invention of claim 83, wherein, for a spherical microphone array, the discrete orthogonality condition of Formula (1) is substantially given by Formula (2) as follows:

$$\delta_{n-n',m-m'} \propto \frac{4\pi}{S}\sum_{s=1}^{S} Y_n^{m*}(\vartheta_s, \varphi_s) Y_{n'}^{m'}(\vartheta_s, \varphi_s), \qquad (2)$$

wherein:

(ϑ_s, φ_s) are spherical coordinate angles of sensor *s* in the microphone array;

$Y_{n'}^{m'}(\vartheta_s, \varphi_s)$ is a spherical harmonic function of order *n'* and degree *m'* at the spherical coordinate angles (ϑ_s, φ_s); and

$Y_n^{m*}(\vartheta_s, \varphi_s)$ is a complex conjugate of the spherical harmonic function of order *n* and degree *m* at the spherical coordinate angles (ϑ_s, φ_s).